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INITIAL STUDIES IN OBJECTIVE FORECASTING OF MESOSCALE WEATHER USING INTERACTIVE COMPUTER SYSTEM

LEVEL II

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Subsynoptic convective areas are isolated, monitored and forecast through extrapolation and advection using McIDAS, an interactive computer video-display system. Research on isolating the convective areas focuses on development of statistics using digital visual and IR GOES satellite data to delineate areal coverage and intensity. McIDAS algorithms have been developed to: 1) compute the brightness centroid; 2) form a best-fit ellipse to the region; and 3) compute areal average IR and normalized-visual brightness. Sequences (over)

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of brightness centers and geometric outlines serve as input to extrapolation routines to project system movement and change in area coverage and intensity. Research also has been initiated on using vertically-integrated wind fields to advect meteorological fields and disturbances. Preliminary results using these techniques for short-range forecast are presented.

ACKNOWLEDGMENTS

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1. INTRODUCTION

The purpose of this report is to describe research conducted at Space Science and Engineering Center (SSEC) under an Air Force Geophysical Laboratory (AFGL) contract during the initial year of investigation. The research objectives are to develop methods of improving short-range terminal weather forecasting techniques through the use of McIDAS (Man-computer Interactive Data Access System) for the processing and application of satellite and conventional meteorological data. Primary emphasis is placed on specifying and forecasting weather features such as ceilings, visibility, precipitation and also rarer events such as severe storms and turbulence.

The McIDAS, the key tool in this research, permits rapid access and display of various types of meteorological data (satellite, surface, radiosonde and radar). Its satellite capabilities include the real time input of digital data, its display with accurate latitude and longitude gridding, enhancement of any portion of the brightness range, and computations with the brightness data. In addition, surface and radiosonde data are available in plotted or analyzed form on either conventional or satellite map projections. Fields of atmospheric structure and dynamical processes can also be displayed. The system provides for the rapid integration of conventional and satellite data and also facilitates computation of simple diagnostic and forecast algorithms. For more details on the McIDAS system, the reader is referred to Hilyard,[1] Chatters and Suomi[2] and Smith.[3]

The first year's work supported by this contract focused on two research objectives:

1. the development of techniques to isolate, monitor and forecast subsynoptic convective areas which

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1. Hilyard, J., editor,(1977) Interactive Video Displays for Atmospheric Studies. Proceedings of a workshop at the University of Wisconsin, Madison, 14-16 June, 1977.
2. Chatters, G. C. and V. E. Suomi (1975) The application of McIDAS, IEEE Trans. Geosci. Electron., GE-13, 137-46.
3. Smith, E. A. (1975) The McIDAS System, IEEE Trans. Geosci. Electron., GE-13, 123-36.

produce aviation hazards such as restricted visibility, low ceilings, precipitation types and high sustained wind and gusts

2. the development of a forecast annunciation system within the interactive McIDAS environment for warning of possible forecast failure or a situation requiring additional forecaster attention due to the probability of imminent weather changes.

Progress towards these two objectives is now reviewed; the new software developed for McIDAS is summarized and future directions of the research effort are outlined.

2. AREAL SPECIFICATION AND FORECAST OF SUBSYNOPTIC CONVECTIVE AREAS

Active weather areas with hazardous surface conditions (low visibilities and ceilings, high wind gusts and precipitation) frequently are associated with vigorous convection. Convective outbreaks often exhibit organization on the subsynoptic scale. Examples of such organization are squall lines, frontal precipitation areas and embedded heavy precipitation bands within the larger scale circulation of the extratropical cyclone. This subsynoptic organization of convection is most clearly seen in visible and infrared satellite data. In particular through the use of McIDAS, geostationary GOES data, with its high temporal and spatial resolution over large geographic regions, is effective in accurately monitoring frontal locations, convective development and movement and the cyclone cloud structure. In contrast, surface reports are often too sparse in time and space to describe evolution of convective systems. Radar provides detailed structure for a distinct region; however, difficulties arise when the convective system is moving from coverage of one radar site to another or extends across several radar station areas. However, through the combination of high temporal and spatial resolution of GOES data with surface observations, radar and other conventional reports, specification of convective areas and forecasts of future movement or development improves.

2.1 Techniques

The techniques developed focused on two tasks: (1) the isolation and delineation of subsynoptic convective area using satellite and conventional data and (2) the monitoring of the area movement, intensity and coverage and prediction of its future evolution.

2.1.1 Isolation and Description

Although McIDAS facilitates the visualization of atmospheric convection, the quantitative delineation of convective areas remains a difficult task. Through the condition that high visual and infrared brightness depict vertically-developed cloudiness, satellite brightness thresholds have been derived for tropical rainfall studies conducted over Florida and the GATE region in the tropical Atlantic (Griffith et al.,[4] Stout et al.[5]). Methods of estimating station rainfall in the central United States using infrared and visible geostationary satellite images have been developed by Schofield and Oliver.[6] However, the guidance on thresholds applicable to isolating mid-latitude convection for different geographical areas is less well established. Surface reports plotted on the satellite image provide some insight into which combination of brightness levels is most effective in outlining convective areas but few quantitative results are available.

Our objective is to determine probability of convective activity, given visual and IR brightness statistics for various geographical regions in the United States along with measures of the uncertainties in the estimates of the extent of convection from satellite data alone.

Efforts have been initiated to develop more detailed statistics relating GOES visible and IR data and Manually Digitized Radar (MDR) to surface reports

4. Griffith, C. G., W. L. Woodley, P. G. Gruber, D. W. Martin, J. Stout and D. N. Sikdar (1978) Rain estimation from geosynchronous satellite imagery - visible and infrared studies, Mon. Wea. Rev., 106, 1153-71.
5. Stout, J. E., D. W. Martin and D. N. Sikdar (1979) Estimating GATE rainfall with geosynchronous satellite images, Mon. Wea. Rev., 107, 585-98.
6. Schofield, R. A., and V. J. Oliver (1977) A scheme for estimating convective rainfall from satellite imagery. NOAA/NESS Technical Memorandum 86, U.S. Dept. of Commerce, NOAA, Washington, D.C.

of convection over different regions. Statistics will be stratified for observation of thunder, various intensities of precipitation and limited visibility and cloud ceilings. The project capitalizes on the McIDAS real time receipt of satellite and conventional weather data. For archive effort programs have been prepared to save 11 x 11 array of GOES visual and Infrared 2 mile satellite data and 3 x 3 array of MDR data centered on surface reports for all reports of broken and overcast cloud conditions.

Interactive programs also have been developed to describe and monitor convective areas using digital satellite data. Computation and brightness centers and the geometric elliptical areas present methods of quantifying satellite data to describe subsynoptic convective areas. The initial step in the forecast procedure is the determination of threshold of normalized-visual and infrared brightness to delineate convective areas in the satellite imagery. The threshold is determined by intercomparing surface reports and MDR data plotted on enhanced satellite imagery. For future work results from the statistical study discussed above will provide more insight on threshold determination.

Interactive computations on the digital satellite data are possible within a movable rectangular cursor of variable dimensions. Several programs were developed to describe and quantify convective regions using the movable cursor. Initially the cursor is positioned to circumscribe the convective regions (Figure 1a). In the case of convective lines, the line may have to be broken into several segments placing breaks preferably over areas of lesser activity (Figure 2a). The centroid of brightness and the average brightness for all pixels above the enhancement threshold are computed for the region. Centroid computation was selected over the geometric center to minimize the effect of cursor location on determining the center of the convective area. A second program computes an objective elliptical fit to the brightness region to provide a simple geometric description of the area (Figures 1b and 2b). The initial elliptical fit is done objectively by determining brightness threshold location on radials every 10 degrees emanating from the brightness center. From this computation the major and minor axes and the orientation of the ellipse are determined. The operator can then change the parameters of ellipses to improve the fit. The measure of goodness of fit is the percentage of pixels above the threshold contained in an ellipse.

2.1.2. Prediction

The disturbance is temporally monitored to determine movement, area growth or decay and intensity changes. Sequences of brightness-weighted centers and geometric outlines produce a measurement of area motion and changes in areal coverage and orientation (Figure 1c). Variations in average normalized-visual and infrared brightness for the area are also monitored for possible indication of intensity change.

Prediction algorithms complete the program package. Extrapolation and advection schemes are used to forecast movement, changes of intensity and areal coverage and orientation. Extrapolation programs using first and second order polynomials produced from "least squares" regression and a Taylor Series exact fit of input path are being tested. Advection scheme moves the disturbed area with current vertically-integrated upper level winds with limits of the vertical integration user specified. The forecasts are evaluated by applying the same enhancement thresholds and computing a brightness centroid and best-fitting ellipse or rectangle to the verification satellite information and computing differences in location and areal skill scores. Scores computed are the threat score, bias and post agreement used by NMC in evaluation of areal precipitation forecasts. These routines have been developed from a study of six cases of dependent data which include a wide range of convective patterns including squall lines, frontal convection, convective areas and embedded convective bands within cloud structure of extratropical cyclone.

2.2 Illustration of Methods

Some initial results using an interactive computer to quantify subsynoptic convective areas with satellite brightness data are presented in Figures 3, 4 and 5. GOES full resolution infrared images of a midwest convective system for 1300, 1400, 1500, 1600 and 2000 GMT 17 June 1978 are depicted in Figure 3. Using a digital count threshold of 47 on the digital infrared data produced an outline of convective regions which agreed well with surface reports of thunder and manually-digitized radar data. The enhanced data depicts three convective areas at 1300 GMT (Figure 3a). The largest area which moves from northern Iowa-southern Minnesota (1300 GMT) to lower Michigan (2000 GMT) will be analyzed first. Results of the brightness computations are presented on Figure 4.

Panel A depicts a plot of the surface weather data and an ellipse fit of the brightness area for 1400 GMT. A sequence of ellipses generated from the infrared brightness pattern (threshold 47) for 1300, 1400, 1500, 1600 and 2000 GMT is shown on Figure 4b. The 2000 GMT ellipse represents the target for which 4 hour forecasts are made from the 1300-1600 GMT sequences of the images. Panels C and D show the verification of linear regression extrapolation of elliptical regions for 2 and 4 hours. The intersection of the predicted and target ellipses is shaded. The verification scores for these forecasts are:

	Threat Score	Bias	Post Agreement
2 hr forecast	.75	.84	.94
4 hr forecast	.64	.88	.83

Areal scores are defined on Table I.

The linear extrapolation accurately forecasts the center of the convective area with errors of 48 km at 2 hours and 62 km at 4 hours. The major source of areal forecast error is orientation of the forecast ellipse. The forecasts, following the input data, project an elliptical area with major axis oriented east-northeast to west-southwest while verification area is nearly circular. Consequently, forecast errors occur on the northern and southern edges of the forecast.

Table I

Threat Score	$A_C/(A_O + A_F - A_C)$
Bias	A_F/A_O
Post Agreement	A_C/A_F

where A_C - area correct

A_O - area observed

A_F - area forecast

A second more complex example is presented in Figure 5. Figure 5a displays enhanced GOES infrared view (level 47) of frontal convection over the

south central United States for 2200 GMT 12 May 1978. Panel B and C display a sequence of ellipses generated from data from 2200 GMT to 0000 GMT and a ;arget ellipse generated from data at 0400 GMT 13 May, a 4 hour forecast. This forecast is verified on Panel D with the intersection of forecast and observed ellipses shaded. The areal scores for this 4 hour forecast are:

	Threat Score	Bias	Post Agreement
4 hr forecast 0-4 GMT 13 May	.48	.48	1.00

The forecast again accurately predicts the movement of the activity. However, the forecast area is smaller than the verification region due to the merger of the convective area with other convective regions to form a long squall line from Tennessee to Texas by 0400 GMT. These examples indicate reasonable skill in 2 and 4 hour linear extrapolation forecasts. Future efforts will be directed toward real time tests of these algorithms.

. FORECASTER ALERT DEVELOPMENT

The second research thrust is the development of a forecaster annunciation system through the use of McIDAS. The forecaster alert function consists of automatically notifying the responsible forecaster when conditions at an air terminal 1) have exceeded specified values, or 2) are likely to exceed specified values shortly. The criteria used to alert the forecaster are commonly based on the current terminal forecast (TAF), field minimum conditions or any other special parameters and criteria.

The basis for the alert function is straight forward; as a new observation is received, it is compared to the specified parameters and criteria. If the comparison indicates that the forecast is no longer valid, the forecaster is presented with a message to alert him of this fact. It would be desirable to use both visual and audible signals. The software to accomplish this has been developed for the McIDAS system environment.

In the second part of the alert function, the forecast of adverse weather to trigger the alert, is a considerably more difficult problem. There are two approaches to the short-range forecast problem:

1. development of single station statistics which relate current parameters to near future changes utilize current conditions plus Model Output Statistics (MOS) type guidance to prepare the forecast

2. development of simple methods to extrapolate or advect current weather systems to determine if adverse weather detected at nearby stations or inferred by satellite or radar observations will affect the station.

In both cases the prediction must be made in near real time; that is, with a data cutoff measured in minutes and a forecast process which does not require significant computing time. A single station statistical approach with conditional probabilities of a future event given the current sequence of observations has been developed by Martin.[7] An example of this use of MOS information with current data to refine the local forecast was described by Grayson.[8]

These approaches, while working well in general weather conditions, give the worst results for the cases which are most critical, the sudden onset of adverse weather. These critical events are often poorly specified by statistical techniques. Thus, the emphasis in this research effort on the second approach, the development of simple methods applicable to interactive mini-computer systems to extrapolate or advect current weather systems.

In the development of an advective model for the McIDAS system, a characteristic wind is used in the advection of an entity or parameter. In our initial work a vertically-integrated, density-weighted characteristic wind is determined. This vertically integrated wind is an estimate of the mean momentum of the atmospheric column. The leapfrog advective scheme proved unacceptable due to truncation problems so a conservative form of the advection scheme is employed:

7. Martin, D. E. (1976) Improved usages of climatology for forecasting ceilings and visibilities 2 and 4 hours in advance. Preprint of Sixth Conference on Weather Forecasting and Analysis of the American Meteorological Society, Boston, MA., 74-77.

8. Grayson, T. H., G. M. Carter, S. Brown and A. Mac Donald (1978) Forecasting high level convection and gusty surface winds in an interactive man-machine experiment. Preprint of Conference on Weather Forecasting and Analysis and Aviation Meteorology of the American Meteorological Society, Boston, MA., 313-19.

$$\text{Advection of } Q = \frac{U_1 + U_2}{2} \left(\frac{Q_2 - Q_1}{\Delta d}\right) + \frac{U_3 + U_2}{2} \left(\frac{Q_3 - Q_2}{\Delta d}\right)$$

where 1, 2, 3 denote adjacent grid points.

Some results of this effort are presented in Figures 6 and 7. On 5 April 1979 an intense cold front moved rapidly across the upper midwest. With the frontal passage, temperature decreased 5°C and convective snow showers and wind gusts of 20-30 ms^{-1} occurred. The surface temperature advection pattern provided a distinct signature of this frontal zone. A cold advection area with a maximum value of 40-50 degrees day^{-1} denotes the front. Figure 6A shows the maximum centered over the Dakotas at 1200 GMT 5 April. Its positions at 1500 and 1800 GMT are found on Figure 7A and C. In six hours the front moved to western Wisconsin, Minnesota, Iowa and Nebraska.

An advective 3, 6 and 9 hr forecast using the characteristic wind is displayed on Figure 6B, C and D. The forecast is verified on Figure 7 at the 3 and 6 hour mark. The advective forecast correctly moves the temperature advection field southeastward; however, the movement of the frontal feature is forecast faster than observed. Also the algorithm does not change the intensity of the advection pattern as observed in this case. This example of preliminary results illustrates the use of advection programs to provide relatively accurate short-range forecast guidance of frontal movement.

4. FUTURE RESEARCH

The first year of work has been devoted to developing techniques for short range forecasts. The programs were developed on a set of case tests for which data was complete and which clearly exhibited critical weather events. During the second year the tools developed will be applied and tested on independent data. Planned experiments using these algorithms will be conducted within semi-operational Mesoscale Laboratory of SSEC for the processing and application of VISSR atmospheric sounder (VAS) data, an application of McIDAS techniques to real-time data.

Several additional inputs to the forecast system will be added in the near future. Work is proceeding on an area movement computation using cross-correlation methods. This is a generalization of the wind estimating techniques used for cloud-drift winds already in operation on McIDAS

(Chatters and Suomi[2]) and follows similar objective procedures applied to digital weather radar data by Bellon and Austin[9] and to satellite data by Muench and Hawkins.[10] Instead of focusing on an individual cloud, the operator will use the enlarged cursor to describe the convective areas and correlation methods will determine objectively the movement of the region between successive pictures. In addition, the magnitude of the correlation coefficient and its rate of decay between sequential images will be studied for its predictability of changes in cloud area and intensity of cloud convection. High correlation values will indicate strong continuity in the structure of the convective system and suggest longer periods of skillful prediction while low correlation values will indicate a rapidly changing system with very limited forecast periods.

A second effort involves the input of conventional data into the convective area forecast. In particular, local averages of surface parameters will be made in conjunction with satellite computations. Surface parameters such as potential temperature, equivalent potential temperature, specific humidity and associated advection and divergence will be evaluated hourly following the moving convective area in a quasi-Lagrangian sense. The value of using the surface variable tendency for forecasting of intensity changes of the convective system will be evaluated.

Efforts on the forecaster alert will continue to be directed toward short-term prediction of existing weather. In the advective scheme, refinements of the characteristic wind appropriate to a particular parameter will be made. In an effort to decrease the amount of computer time required, code will be implemented to compute backward trajectories, emanating from the point of interest, using the appropriate characteristic wind. Testing of the advective scheme for a number of parameters will be initiated shortly with both case study and semi-operational mesoscale lab data.

9. Bellon, A. and G. L. Austin (1978) The Evaluation of Real-time Operation of a Short-term Precipitation Forecasting Procedure (SHARP), J. Appl. Meteor., 17, 1778-87.

10. Muench, H. Stuart and R. S. Hawkins (1979) Short-range forecasting through Extrapolation of Satellite Imagery Patterns. AFGL-TR-79-0096, 26 April 1979.

5. SUMMARY

This report describes current research on isolating, monitoring and forecasting subsynoptic convective areas using an interactive computer video-display system. Work in isolating the convection areas focuses on development of statistics using digital visual and IR satellite data to estimate coverage and intensity of convective areas. In addition, McIDAS algorithms have been developed to 1) compute the brightness centroid of activity, 2) form a best-fitting ellipse to the region and 3) compute areal average infrared and normalized-visual brightness which then serve as input to extrapolation routines to project system movement and change in area coverage and intensity. Research also has been initiated on using vertically-integrated wind fields to advect meteorological fields and disturbances. This first year has been one of primarily developing techniques for using McIDAS and satellite data for short-range forecasts. Extensive testing of these programs will be emphasized in the second year of research.

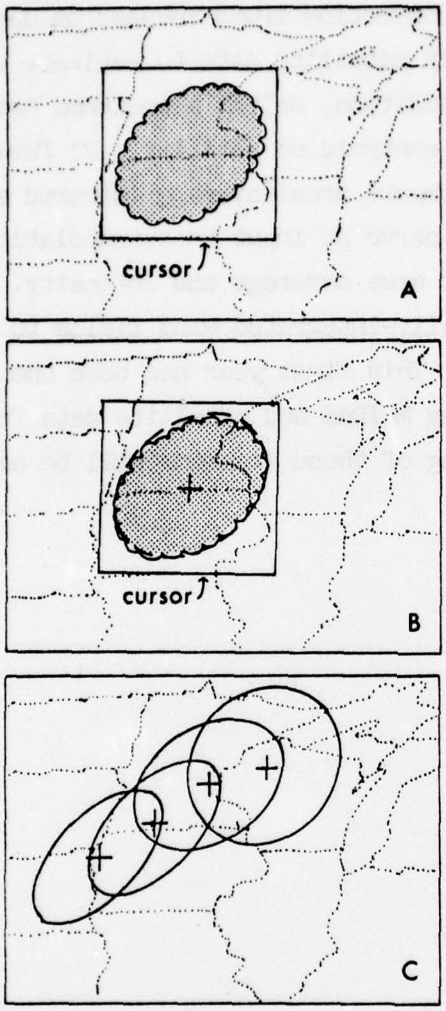

Figure 1.

a. Cursor circumscribing convective region on satellite image.
b. Best-fit ellipse for convective region.
c. Sequence of ellipses over four time periods to measure area motion and changes in areal coverage and orientation.

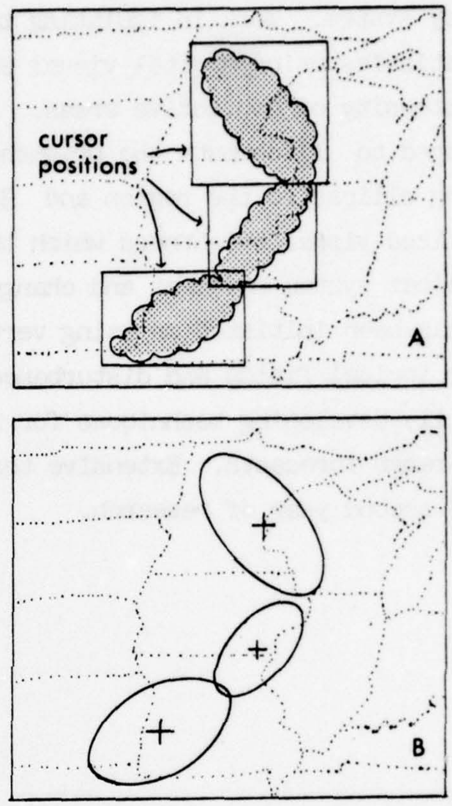

Figure 2.

a. Partitioning of convective line with three successive cursor positions.
b. Centroids of brightness and best-fitting ellipses for the convective line.

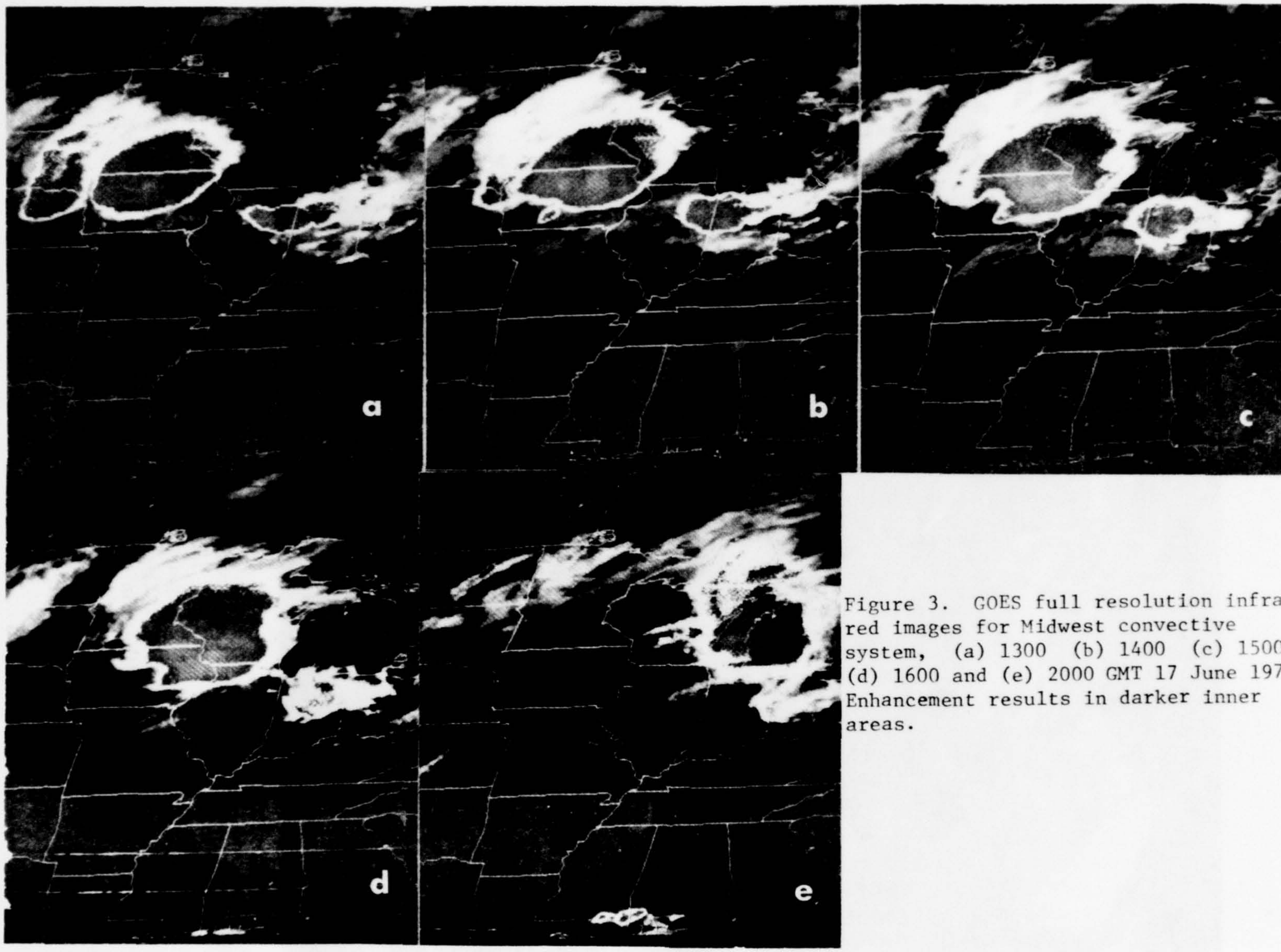

Figure 3. GOES full resolution infrared images for Midwest convective system, (a) 1300 (b) 1400 (c) 1500 (d) 1600 and (e) 2000 GMT 17 June 1978. Enhancement results in darker inner areas.

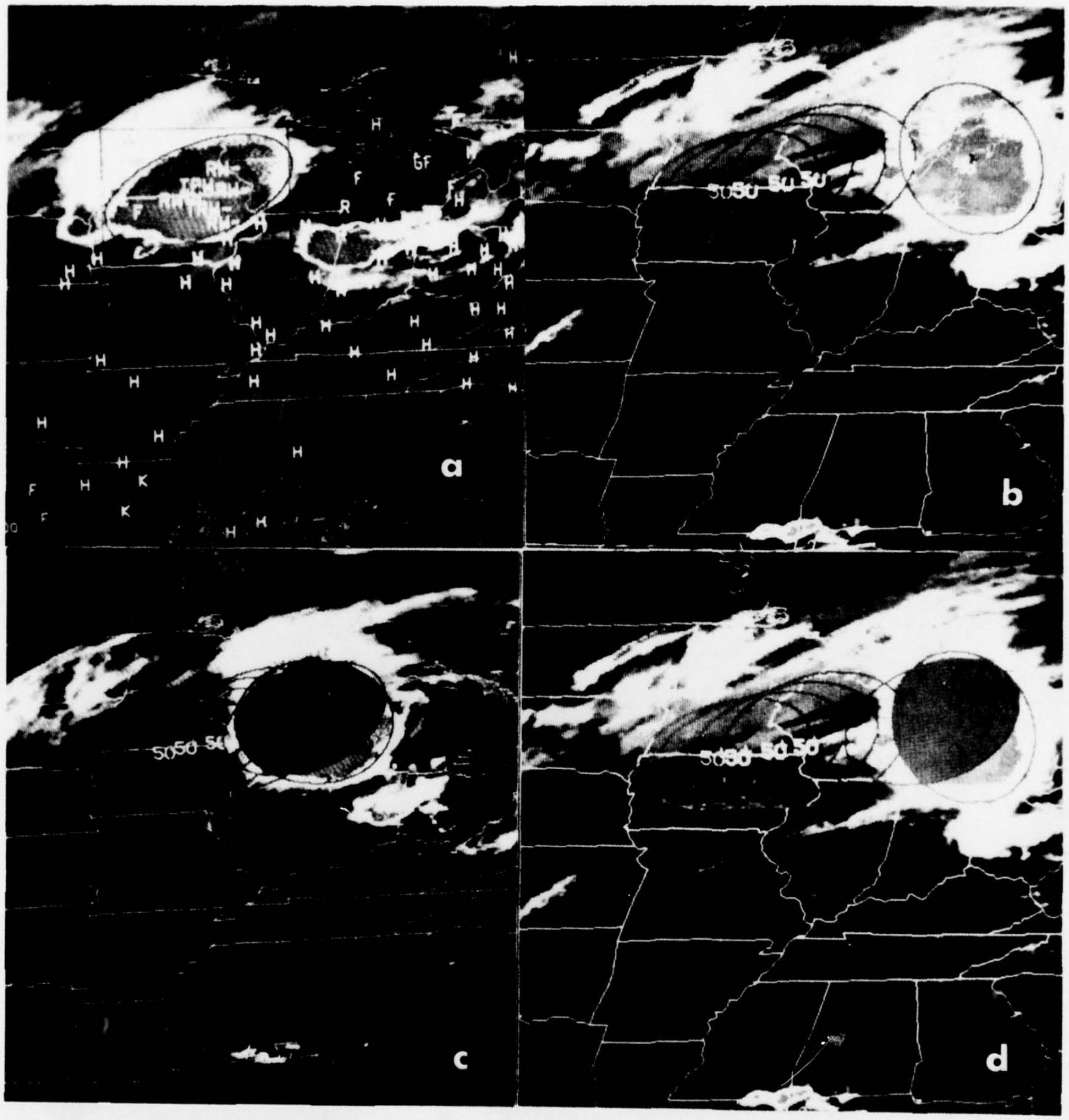

Figure 4. a. Surface weather data and an ellipse fit of the brightness area for 1400 GMT 17 June 1978.
b. Sequence of ellipses generated from brightness patterns for 1300, 1400, 1500, 1600 and 2000 GMT.
c. & d. Verification of linear regression extrapolation for 2 (c) and 4 (d) hours.

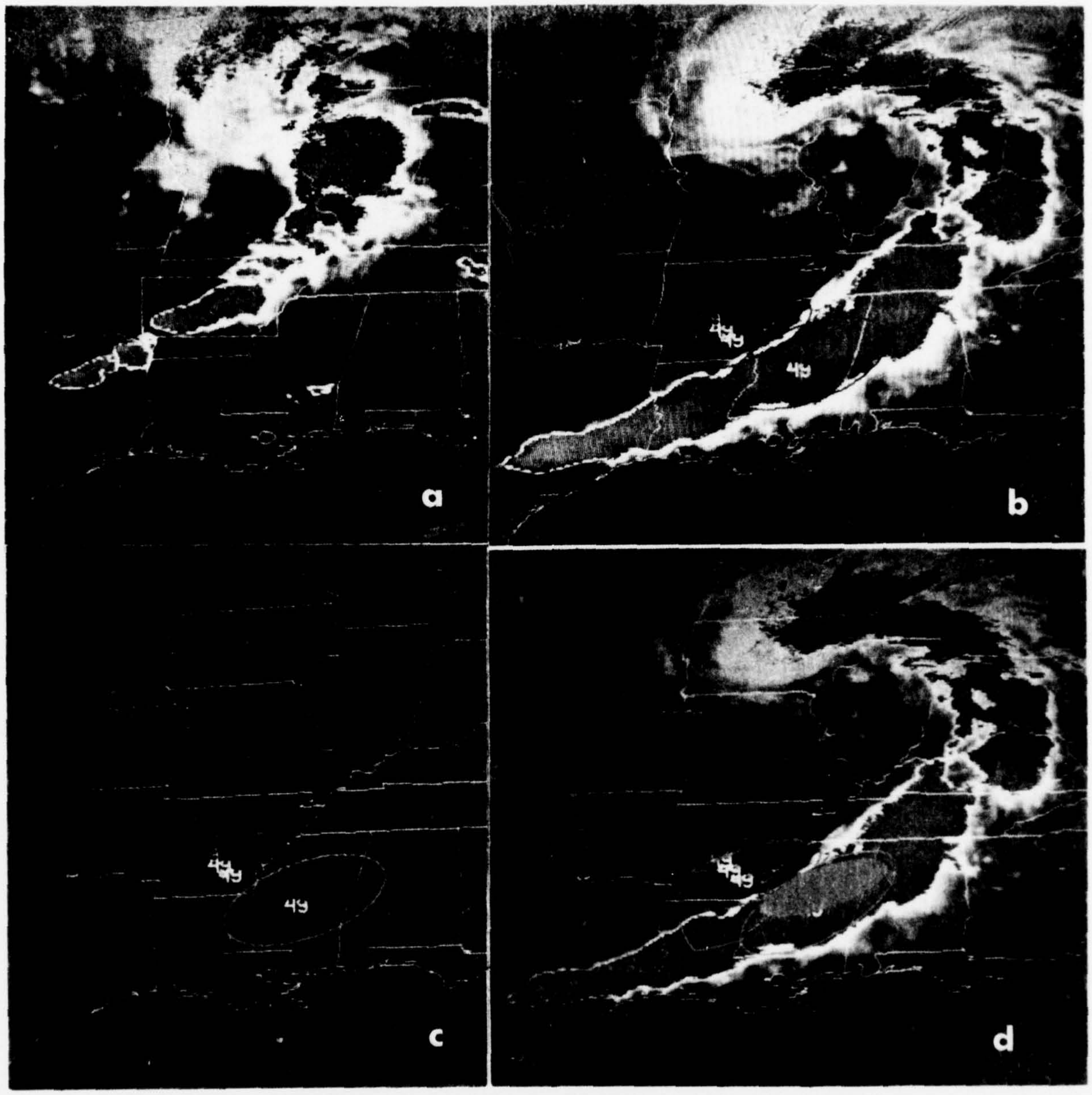

Figure 5. a. Enhanced GOES infrared imagery of frontal convection over south central U.S., 2200 GMT 12 May 1978.

b. & c. Sequences of ellipses generated from data at 2200, 2300 and 0000 GMT 12-13 May and Target Ellipse at 0400 GMT 13 May.

d. Verification of linear regression extrapolation for 4 hour forecast verifying at 0400 GMT 13 May.

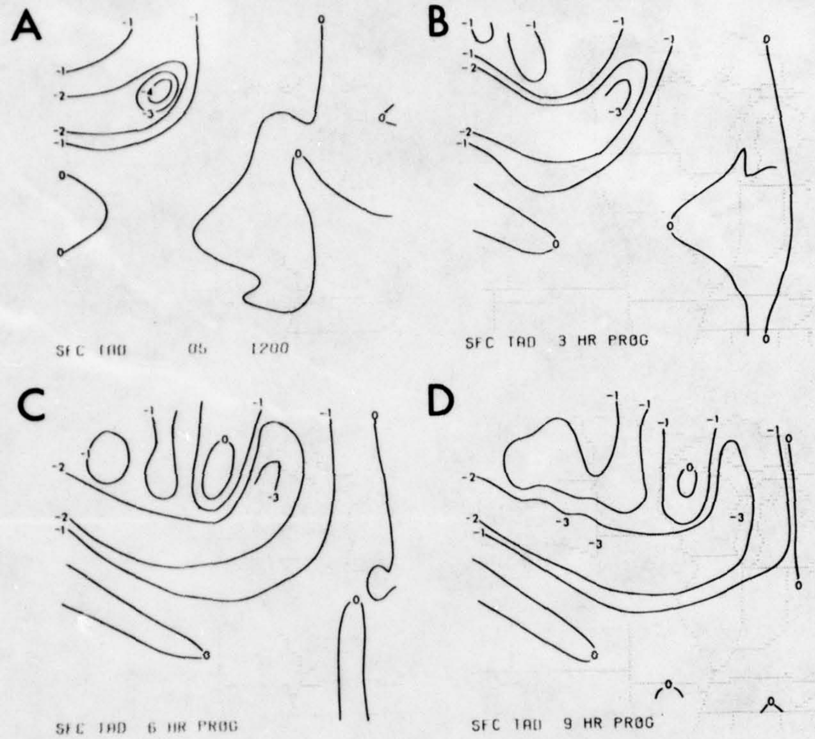

Figure 6. a. Observed surface temperature advection 1200 GMT 5 April 1979 ($10^{o}C$ day^{-1}).
b. 3 hour temperature advection forecast.
c. 6 hour advection forecast.
d. 9 hour advection forecast.

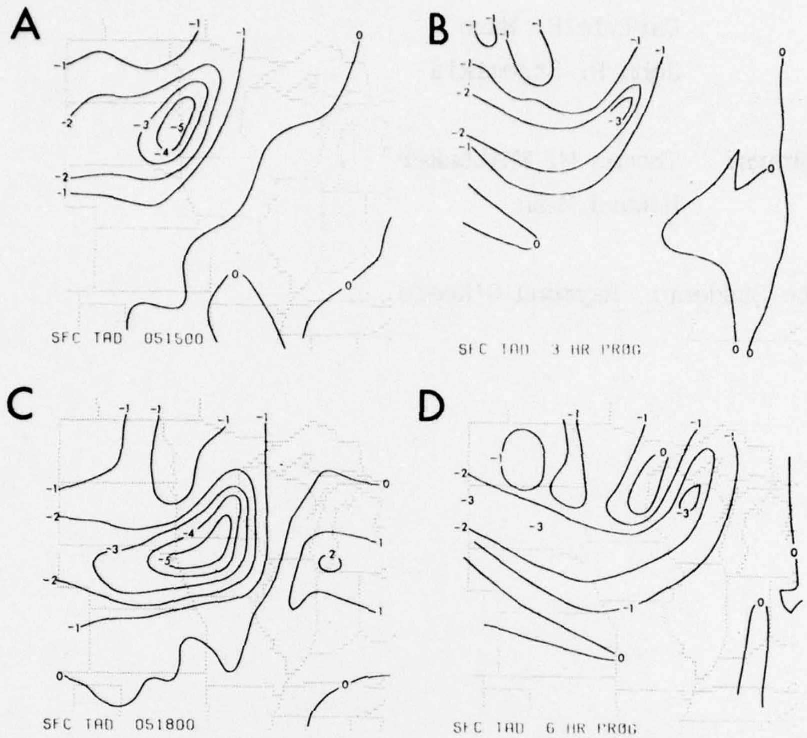

Figure 7. a. Observed temperature advection 1500 GMT 5 April 1979.
b. 3 hour temperature advection forecast verifying at 1500 GMT.
c. Observed temperature advection 1800 GMT 5 April 1979.
d. 6 hour temperature advection forecast verifying at 1800 GMT.

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John R. Stremikis

Programmers: Thomas M. Whittaker
Howard Mead

Graduate Student: Raymond O'Keefe

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